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Scheduling-based real time energy flow control strategy for building energy management system

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ABSTRACT

We propose a novel strategy for BEMS (Building Energy Management System), which efficiently controls energy flows in a building so as to minimize the total cost of energy for a finite period. We also consider Demand Response (DR) events during the period. The proposed strategy includes prediction, long-term scheduling, and real-time control (RTC) of components within a building. During the period, the process from prediction to RTC is iterated in every time unit when the system status is changed by a dynamic environment. The scheduler determines the optimal energy flows based on the prediction, and RTC utilizes the scheduling result so that the energy flow can be adaptively controlled in a dynamic environment. Finally, the system status change information is fed back for the next iteration. Simulation results indicate potential cost savings that are approximately 10–20% compared to a typical BEMS with a conventional RTC scheme.

1. Introduction

In the power system areas, there have been enormous efforts on efficient energy management in order to resolve problems incurred from the energy crises. The concept of the Smart Grid is one of the solutions to those problems. In Smart Grid systems, all the information of every grid component should be accessible and all the components composing the power grid should be controlled by two-way communication [1]. Besides the infrastructures and facilities, there have been other efforts on electricity pricing policies [2]. Real-time pricing is one of the well-known policies for dealing with peak energy consumption. In this pricing scheme, the electricity pricing rate is available for customers one hour to one day in advance. Thus, customers can manage the usage of their electric devices in order to minimize the total electricity cost. For example, they can control the target temperatures in air conditioners or electric heating appliances, or brightness of light bulbs based on the electricity pricing rates [3]. In addition, DR incentive policy has been effectively used as a scheme for reducing peak load usage. Customers who participate in the DR events may receive benefits and incentives from power utility companies when the utilities announce the DR event [4]. While there are various optimization strategies and polices for reducing energy consumption [5–7], they mainly focus on controlling passive components such as load control and shift but not active components such as renewable energy sources.

In addition to nationwide efforts on energy management, strategies for small size power grids have been actively discussed. Microgrid is the downscaled cells of the Smart Grid [8]. Microgrid can be operated as a dispatchable load of the conventional power system as well as an independent power system for small-scale areas. By considering distributed energy resources (DER), such as wind and solar, and energy storage system (ESS) in conjunction with scheduling and RTC schemes, Microgrid can achieve several advantages such as enhancement of local reliability, reduction of feeder losses, and increased efficiency whose main purpose is to minimize either the total electricity cost or CO_2 emission from the designed Microgrid. For load control, Microgrid and Smart Grid are able to encourage customers to participate in peak power consumption control, which results in load reduction. However, this action is very limited; it is highly likely for customers not to reduce their power consumption. On the other hand, the load in buildings can be controlled directly by BEMS, so that the strategy for the building is different with that of the Microgrid.

Alternative efforts for efficient energy management have also been discussed in areas smaller than Microgrid, where the most

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representative example is BEMS [9]. The basic concept of the small sized Microgrid has been applied to homes, buildings, and industrial plants [10]. Unlike in the past, where passive components were the dominant energy consumption load, the more recent end components have become active. This means that they may have intelligence with regards to energy management, so that the scheduling and RTC can include renewable energy, ESS, and load controls with feedback information [11]. One key part of BEMS is the HVAC (Heating Ventilating Air Conditioning) system, which has been studied in [12,13]. In HVAC, model predictive control (MPC) is widely deployed for its simplicity – if a system is modeled, the complexity required for its implementation can be significantly reduced [14,15]. Moreover, MPC has been used to control energy flows in Microgrid [16–18] and household environments [19]. A general MPC scheme is not suitable for event driven situations, i.e. a target event such as DR event should be accomplished for a short period of time. This is mainly because of the static time window size (i.e., the time horizon considered for future energy flow scheduling optimization). In addition, since the general MPC does not include an RTC scheme, the stable energy flow control may not be accurately optimized in a dynamically changing environment.

In order to overcome these limitations of prior works, the proposed framework includes prediction, long-term scheduling and RTC. The main contributions of this paper are summarized as follows. The proposed long-term scheduling and RTC of energy flow (such as energy to/from the grid, energy to/from the ESS, and load shift) in a building equipped with renewable power generators and ESS: (i) addressing prediction on pricing, renewable energy, and load pattern to formulate the optimization problem for long term scheduling, (ii) considering management scheme for special events such as DR event, and (iii) addressing hour-based parameter setup of RTC for stable control against to dynamics such as load and renewable energy fluctuation. In our simulations, we show that the proposed approach can reduce total electricity cost by approximately 15% compared to conventional RTC strategies.

The remainder of this paper is organized as follows. In Section 2, the overview of the considered framework is presented. In Section 3, the scheduling algorithm and RTC scheme are proposed. In Section 4, the performance evaluation of the proposed framework is discussed with a set of actual measured and collected data in Seoul, Republic of Korea, and the conclusion is drawn in Section 5.

2. Overview of the framework

2.1. Brief overview of BEMS

In this paper, we consider a building energy system shown in Fig. 1, where it consists of the components such as DERs, ESS and loads, and these are controlled by the BEMS. The power lines are connected to a power grid. The loads in the building can be categorized into base type or controllable type. Several fixed facilities and servers in the building may be considered as the base type. The controllable type may include electric heating appliances and air conditioning systems, where the loads from the controllable type can be scheduled and controlled by BEMS with a deployed energy management strategy. BEMS collects the information from both inside and outside of the building, which includes the recent status of all components of the building (from inside of the building) and the current pricing rate, climate status, etc. (from outside of the building). Such information can be exchanged and shared based on the network infrastructures (e.g., power line communication, Zigbee, conventional wired/wireless networks, etc.). Based on the collected information, BEMS performs the management of energy in the building in order to minimize either running cost or CO_2 emission.

2.2. The framework of the proposed BEMS

The main focus of this paper is on BEMS, in particular a new proposed framework of BEMS, and its components such as prediction, long-term scheduling and RTC strategies. Fig. 2 shows the proposed framework of BEMS. The main objective of the proposed BEMS is the minimization of total cost for electricity which is consumed for a specific period (in general 1–15 days). Before the long term scheduling, future electricity pricing, future renewable power generation, and future load usage pattern should be forecasted for the next N hours; N is the product of 24 h and the considered days. Based on the historical data of pricing, renewable power, and load pattern,

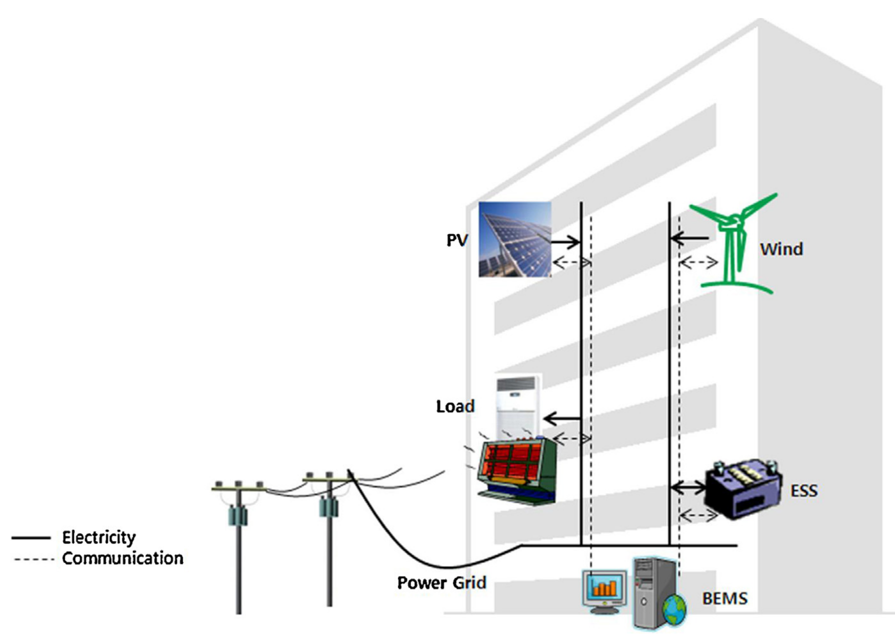

Fig. 1. Energy system of buildings.